Radiative decay of single charmed baryons

Ajay Majethiya† [1], Bhavin Patel ‡ and P C Vinodkumar‡
† ‡Department of Physics, Sardar Patel University,
Vallabh Vidyanagar, Anand, Gujarat-388 120.
†Kalol Institute of Technology and Research Center,Gujarat University,
Kalol, Gujarat-382 721.

Abstract

The electromagnetic transitions between ($J^P = \frac{3}{2}^+$) and ($J^P = \frac{1}{2}^+$) baryons are important decay modes to observe new hadronic states experimentally. For the estimation of these transitions widths, we employ a non-relativistic quark potential model description with color coulomb plus linear confinement potential. Such a description has been employed to compute the ground state masses and magnetic moments of the single heavy flavor baryons. The magnetic moments of the baryons are obtained using the spin-flavor structure of the constituting quark composition of the baryon. Here, we also define an effective constituent mass of the quarks (ecqm) by taking into account the binding effects of the quarks within the baryon. The radiative transition widths are computed in terms of the magnetic moments of the baryon and the photon energy. Our results are compared with other theoretical models.

1 Introduction

Recent experimental observations of excited charmed baryons by Belle and Babar collaborations have generated [1, 2] an increasing interest on heavy-baryon spectroscopy. It is striking that baryons containing one or two heavy charm or beauty flavour could play an important role in our understanding of QCD at the hadronic scale [3]. Apart from spectroscopy, various decay processes of the heavy flavour baryons are more important to observe new hadronic states experimentally. The strong decays are expected to dominate the branching rates of charmed baryons. In fact, most of the experimentally discovered channels of ground state charmed baryons are the one- and two- pion transitions [4]. Although the electromagnetic strength is weaker than that of the strong interaction, radiative channels are not phase space suppressed as in the case of pion transitions. Therefore, some radiative decay modes are expected to contribute significantly to some heavy baryon branching fractions. The recent observations of CLEO confirm the importance of the radiative channels even though

[1] ajay.phy@gmail.com

their contributions to some heavy baryon widths are relatively small compared to other decay modes. Many theoretical models have predicted the heavy baryon mass spectrum [6, 5, 7, 8, 9, 10, 11, 12, 13, 14]. Nevertheless, the new experimental data of the charmed baryons can be used to test the success and validity of the different phenomenological models available in the literature. The study of heavy baryons further provides excellent laboratory to understand the dynamics of light quarks in the vicinity of heavy flavour quark as bound states.

Although radiative decays are well measured in the case of $D^* \to D\gamma$, $D_s^+ \to D_s^+\gamma$, only very few cases of $\Xi_c^{'0} \to \Xi_c^0 + \gamma$, $\Xi_c^{'+} \to \Xi_c^+ + \gamma$ and $\Omega_c^{*0} \to \Omega_c^0 + \gamma$, have been reported [15]. It may be noted that the nonrelativistic quark model predictions for the magnetic moments of ordinary baryons are in good agreement with their experimental values; in particular, it gives a reasonable value for the transition rate $\Sigma^0 \to \Lambda^0 + \gamma$. It is therefore reasonable to assume that the estimates of the radiative decays based on the nonrelativistic quark model is reliable.

In this paper, we compute the masses and magnetic moments of the single charmed baryons using coloumb plus linear as the confinement inter-quark potential in a non-relativistic framework. The magnetic moments of the baryons are obtained using the spin-flavor structure of the constituent quark mass (cqm) parameters employed in the model as well as with an effective constituent mass of the quarks (ecqm) by taking into account the binding effects of the quarks constituting the baryon. We use the present values of magnetic moments of charmed baryons to obtain the radiative transition widths.

2 Methodology

We start with the color singlet Hamiltonian of the system as

$$H = -\sum_{i=1}^{3} \frac{\nabla_i^2}{2m_i} + \sum_{i<j} V_{ij} \tag{1}$$

Where, the interquark potential

$$V_{ij} = -\tfrac{2\alpha_s}{3}\tfrac{1}{x_{ij}} + \beta\ x_{ij} + V_{spin}(ij);$$

Here, α_s is the running strong coupling constant, β is the potential strength of the baryonic system and V_{spin} is the spin dependent part of the two body system. For the present study, we considered $\alpha_s(\mu_0 = 1GeV) \approx 0.7$. All other parameters of the model including the quark masses are obtained from the study of mass spectra of the singly charmed baryons [16].

Table 1: Radiative decay widths (Γ_γ) of singly charmed baryons in terms of KeV (* indicates $J^P = \frac{3}{2}^+$ state.)

Decay	μ (in μ_N)	Present		HCM		Others
		(ecqm)	(cqm)	(ecqm)	(cqm)	
$\Sigma_c^+ \to \Lambda_c^+$	$-\frac{1}{\sqrt{3}}(\mu_u - \mu_d)$	60.55	85.59	97.98	104.03	98.70[17]
						60.70[18]
						87.00[19]
						89.00[20]
$\Sigma_c^{*++} \to \Sigma_c^{++}$	$-\frac{2\sqrt{2}}{3}(\mu_u - \mu_c)$	1.15	1.71	1.98	2.22	1.70[17]
						3.04[19]
$\Sigma_c^{*+} \to \Sigma_c^+$	$\frac{\sqrt{2}}{3}(\mu_u + \mu_d - 2\mu_c)$	0.00006	0.000079	0.0112	0.0125	0.01[17]
						0.14[18]
						0.19[19]
$\Sigma_c^{*0} \to \Sigma_c^0$	$\frac{2\sqrt{2}}{3}(\mu_d - \mu_c)$	1.12	1.66	1.44	1.60	1.20[17]
$\Sigma_c^{*+} \to \Lambda_c^+$	$\frac{\sqrt{2}}{\sqrt{3}}(\mu_u - \mu_d)$	154.48	229.85	244.39	273.48	250.00[17]
						151.00[18]
						230.00[20]
$\Omega_c^{*0} \to \Omega_c^0$	$\frac{\sqrt{2}}{3}(\mu_s - \mu_c)$	2.02	3.13	0.82	0.79	0.36[17]
$\Xi_c^{*+} \to \Xi_c^+$	$\frac{\sqrt{2}}{3}(\mu_u - \mu_s)$	63.32	96.34	99.94	110.77	124.00[17]
						75.60[20]
$\Xi_c^{*0} \to \Xi_c^0$	$\frac{\sqrt{2}}{\sqrt{3}}(\mu_u - \mu_s)$	0.30	0.46	1.15	1.27	0.80[17]
						0.90[20]

3 Radiative decay of single charmed baryons

The electromagnetic radiative decay width can be expressed in terms of the radiative transition magnetic moment(in μ_N) and photon energy (k) as [17]

$$\Gamma_\gamma = \frac{k^3}{4\pi}\frac{2}{2J+1}\frac{e^2}{m_p^2}\mu^2 \tag{2}$$

here, m_p is the proton mass, μ is the radiative transition magnetic moments (in nuclear magnetons), which are expressed in terms of the magnetic moments of the constituting quarks (μ_q) of the initial state of the Baryon [17]. The magnetic moment of the constituting quarks are obtained as [11]

$$\mu_q = \left\langle \phi_{sf} \mid \frac{e_i}{2m_q^{eff}}\overrightarrow{\sigma}_i \mid \phi_{sf} \right\rangle \tag{3}$$

where, e_i and σ_i represents the charge and the spin of the quarks forming the baryonic state. We have employed the spin flavour wavefunction ($|\phi_{sf}\rangle$) of the symmetric and antisymmetric states of the baryons as used in [11]. Here, m_q^{eff} corresponds to mass of the bound quark inside the baryons taking in to account of its binding interactions with other two quarks described by the Hamiltonian given in Eqn 1. The effective mass for each of the constituting quark $m_{q_i}^{eff}$ can be defined as [11]

$$m_{q_i}^{eff} = m_i \left(1 + \frac{\langle H \rangle}{\sum\limits_i m_i}\right) \tag{4}$$

where, $\langle H \rangle = E + \langle V_{spin} \rangle$ such that the corresponding mass of the baryon with spin angular momentum, J is given by

$$M_B^J = \sum_i m_i + \langle H \rangle = \sum_i m_i^{eff} \tag{5}$$

Here, m_i's are the model quark mass parameters.
Accordingly, the effective mass of the u and d quarks are obtained from the baryonic states of udc. Using the mass spectra and the magnetic moments of the charmed baryons, we compute the transition decay widths with and without considering the effective constituent masses of the quarks. We have also computed the transition widths using the predicted magnetic moments and masses based on a hyper central model (HCM) [11] for comparision.

4 Conclusion and discussion

We have employed a simple nonrelativistic variational approach with coulomb plus linear potential to compute the radiative decay of the single heavy flavour baryons in terms of radiative transition magnetic moments and photon energy. The model parameters are obtained to get the ground state masses of the cqq systems [16]. The computed radiative transition widths are listed in Table 1 and compared with other theoretical models. Our results tabulated below are found to be in accordance with other model predictions. It can also be seen that our predictions with the effective mass of the quarks within the baryons are in better agreement with the predictions of ref.[18], while these without the effective mass correction are close to the predictions of ref.[20] in general. How ever the hypercentral model predictions with the effective quark mass are in agreement with that of ref.[17]. The future experimental results on these transition widths can only resolve these variations among different model predictions.

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References

[1] Mizuk R *et al.* (Belle Collaboration) Phys. Rev. Lett. **98**, 012001 (2007).

[2] Aubert B *et al.* (BABAR Collaboration) Phys. Rev. Lett. **98**, 122011 (2007).

[3] H Garcilazo *et al.*, J.Phys.G: Nucl. Part. Phys. **34**, 961-976(2007).

[4] G. Brandenburg *et al.*, CLEO Collaboration, Phys. Rev. Lett 78, 2304(1997).

[5] W. Roberts *et al.*, arXiv:nucl-th/0711.2492v1,(2007).

[6] Chien-Wen Hwang, J.Phys.G: Nucl. Part. Phys. **35**, 075003(2008).

[7] Amand Faessler *et al.*, Phys. Rev.D**73**, 094013 (2006).

[8] M. M. Giannini *et al.*, Eur. Phys. J.A **12**, 447-452 (2001).

[9] D. Ebert *et al*, Phys. Rev. D **72**, 034026 (2005).

[10] Yu. Jia, JHEP **10**, 073 (2006).

[11] B Patel *et al.*, J.Phy.G.: Nucl. Part. Phys. **35**, 065001 (2008).

[12] Silvestre-Brac, Prog.Part. Nucl.Phys. Vol. **36**, 263, (1996).

[13] E. Santopinto *et al.* , Eur.Phys. J.A **1**, 307 (1998).

[14] J. L. Rosner, J.Phy.G.: Nucl. Part. Phys. **34**, S127 (2007).

[15] Yao W M *et al.*, Review of Particle Physics(Particle Data Group), J. Phy. G : Nucl Part. Phy. **33** (2006).

[16] Ajay Majethiya *et al.*,arXiv:hep-th/0805.3439v2,(2008)(Accepted for publication in EPJA).

[17] J. Dey *et al.*, Phys. Lett B, 337, 185-188(1994).

[18] M. A. Ivanov *et al.*, Phys. Rev.D**56**, 348 (1998).

[19] S. Tawfiq *et al.*, Phys. Rev.D**63**, 034005 (2001).

[20] Fayyazuddin *et al.*, Modern Physics Lett. A **12**, 1791(1994).